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(54) ELECTRICAL RESISTANCE FURNACES

(71) We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation established by Statute, of Kingsgate House, 66-74 Victoria Street, London, S.W.1., to hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electrical resistance furnaces suitable for a continuous progressive heat treatment process such as the drawing of glass or silica fibres.

The general technique of manufacturing glass fibre is well established but the production of fibres for use in optical communication presents special problems. It is important that such fibres should be optically and dimensionally uniform and that the material should be free from contamination. It becomes increasingly difficult to satisfy these conditions for higher melting point materials such as the hard glasses and particularly for silica which requires a furnace temperature of up to 2200°C. Non-electrical methods and induction heating have been used but resistance heating, although providing the most precisely controllable form of heat input has not been generally adopted. This is because the design of resistance furnaces according to current practice does not enable the required high temperature to be maintained stably in a small well-defined zone to which there is access from the atmosphere.

It is an object of the invention to provide a resistance furnace which is improved in these aspects.

According to the invention an electrical resistance furnace comprises a cylindrical graphite shell, so arranged that in operation the axis of the shell is vertical, the shell having a first portion bounded by one end of the shell and by a diametric plane at which the wall of the shell is pierced by a plurality of uniformly disposed circumferentially extending slots and having a second portion bounded by the other end of the shell and by the diametric plane, the wall of the first portion being pierced by a set of longitudinal slots extending from the circumferential slots and a further set of longitudinal slots extending from said one end, the sets being uniformly interdigitated, to provide a heating element following a regularly meandering resistive path effective to produce a circumferentially substantially uniform heating zone, the wall of the second portion being pierced by a plurality of longitudinal slots uniformly spaced apart and each extending from said other end to a respective one of said circumferential slots, the remaining wall portions providing a like plurality of current conductors connected to the heating element, means for externally connecting said conductors at said other end of the shell, means for continuously enabling process material to be passed axially within the heating element from the upper end of the furnace, means for enabling material that has been processed within the heating element to be withdrawn continuously from the lower end of the furnace, and means for providing an inert gas atmosphere in the furnace.

Preferably the furnace includes means for suspending the shell within the furnace, the heating element portion of the shell lying below the current conductor portion of the shell.

Preferably the means for providing an inert gas atmosphere in the furnace includes gas inlet means and gas outlet means enabling process material being passed into the heating element to be enveloped in cool gas flowing in the same direction and enabling processed material

being withdrawn from the heating element to be enveloped in cool gas flowing in the opposite direction.

In order that the gas flows should be non-turbulent the gas inlet means for each required direction of gas flow may comprise a circumferential passage formed between two parallel conical surfaces arranged to produce the required direction of gas flow and co-axial with the heating element.

Preferably the gases are extracted at an outlet comprising a circumferential aperture coaxial with and at a level immediately below the heating element.

Preferably iris diaphragms are provided at the upper and lower ends of the furnace to enable process material to be passed axially within the heating element from the upper end and to enable material that has been processed to be withdrawn from the lower end, by means of which diaphragms the rate of gas leakage during operation is minimised. The upper diaphragm may also be arranged to apply radial forces to preformed process material entering the furnace such that the process material is constrained to pass along the axis of the furnace.

It will be readily appreciated that the presence of an inert gas atmosphere prevents contamination of the process material at high temperature and that the abovementioned structural and gas flow features operate to provide a stable and advantageous temperature distribution.

An embodiment of the invention will now be described with reference to the accompanying drawing which represents a sectional view of a furnace according to the invention.

Referring to the drawing the heating element 1 for a furnace is formed at the lower end of a cylindrical graphite shell 2 by making two regular sequences of radial slots 3 and 4 through the cylindrical wall. These slots extend longitudinally in a uniformly interdigitated pattern which extends from the lower edge 5 of the cylinder 2 up to a diametric plane which contains two symmetrically disposed circumferential slots 6, through the wall of the cylinder 2, each occupying a sector of less than 180°. Each of the slots 3 extends from the edge 5 to a distance which may be denoted in value by *d* from one of the slots 6 and each of the slots 4 extends from the related one of the slots 6 to a distance *d* from the edge 5. The spacing between adjacent slots 3 and 4 is also made equal to *d* so that a continuous, meandering and uniformly resistive path is formed in the wall of the cylinder 2. The slots 3 and 4 are made as narrow as is consistent with adequate clearance at operating temperature. The thickness of the graphite wall forming the element 1 determines the resistance of the element 1 and is chosen to satisfy the required conditions of supply voltage and current. A low voltage supply is preferable to avoid the possibility of arcing between closely spaced surfaces at high temperature and 30 volts is suitable for the range of power required. The graphite used for the cylinder 2 should be a high purity grade of small grain size in order to give low porosity, high strength and high resistance to oxidation although it is normally protected by inert gas. To enable the temperature to be rapidly and accurately controlled the heated zone should be of limited and closely defined extent and this condition can be more easily satisfied if the length and diameter of the heating element 1 are made similar in dimension. The heating element 1 has been made approximately one inch in length and diameter with a resistive path of approximate cross-section 0.10″ x 0.15″.

The upper portion of the cylinder 2 has two longitudinal slots 7 each extending from the upper edge 8 of the cylinder 2 to intersect one of the circumferential slots 6 midway along its length. The semi-cylindrical members 9 so formed have each a connecting path to the element 1 through a respective one of the gaps between the slots 6 and serve as current conductors from an external supply to the element 1. The current conductors 9 are sufficiently thick-walled to provide a path of low electrical resistance without causing a serious degree of heat loss by conduction from the element 1. The slots 7 are made narrow so that the cylindrical form of the two members 9 is preserved as an essential factor in the maintenance of stable thermal conditions, above the heated zone. For the same reason the upper portion of the cylinder 2 is made comparatively long in relation to its diameter, a ratio of 2:1 being suitable.

The cylinder 2 is designed to be suspended from a flange 10 on its upper edge 8 which, since it is divided on a diameter by slots 7, requires to be mechanically stabilised to prevent closure of the slots 7. It also requires electrical and thermal insulation. A ceramic ring 11 which satisfies these requirements is screwed to the upper face of the flange 10, symmetrically with respect to the two current conductors 9, the head of each of two screws 12 being recessed in the upper surface of the ring 11. Preparatory to mounting the element assembly in the furnace the flange 10 and ring 11 are clamped under spring loading by four bolts (not shown) to a pair of terminal plates (not shown) symmetrically disposed on the upper surface of the ring 11.

The bolts are arranged so that each of the plates is electrically connected to one of the members 9. Each plate carries a vertically mounted terminal stud 14. The screws 12 are preferably used only as temporary aids during assembly and can be removed as the flange 10 and ring 11 are bolted to the terminal plates.

The casing of the furnace comprises a cylindrical wall 15 welded to a base-plate 16 and demountably sealed by an O-ring 17 to a top-plate 18, all the surfaces being water-cooled. The casing components 15, 16 and 18 and all metal components to be referred to later in this description are made from stainless steel. The top-plate 18 has a central hole 19, of diameter equal to the inside diameter of the cylinder 2, the upper edge of which is chamfered at 45° to give the face 20. Mounted on the top-plate 18 is an annular gas inlet chamber 21 to which a gas supply pipe 22 is connected, the inner wall of the chamber 21 forming a passage 23 of the same internal diameter as the hole 19 through which a feedstock rod can be advanced to the heating zone.

The lower end of the passage 23 is extended to within a short distance of the top-plate 18, the passage wall being chamfered so that its face 24 is parallel to the face 20 to give a downwardly and inwardly inclined annular slot through which gas can flow from the chamber 21, without turbulence. The column 23 is extended upwardly to an inlet port, access to which is controlled by a spring loaded iris diaphragm 25. The term "iris diaphragm" is used to denote generally a mechanism for providing an axial aperture of variable size. When it is spring loaded the iris will automatically tend to close. Caps (not shown) are used to seal off the upper and lower ends of the furnace when fibre-drawing is not in progress and the whole enclosure can be evacuated through one of such caps to remove all traces of oxygen before the inert gas is admitted.

The element assembly is mounted in the furnace by locating the ceramic ring 11 on a step on the underside of the top plate 18 concentric with the hole 19. The terminal studs 14 are passed upwards through clearance holes in the top plate 18 and through holes having insulating sealing bushes in the upper face of the gas inlet chamber 21 to form spring-loaded terminals 26 for connection to a power supply. The element assembly now lies axially in the furnace casing with the heating element 1 centrally between the base-plate 16 and top-plate 18. A thin walled graphite heat-shielding cylinder 27 the inside diameter of which is slightly larger than the outside diameter of the cylinder 2 is mounted on the base-plate 16 concentric with the cylinder 2 and ex- flange 10. The wall of the cylinder 27 is tends to within a short distance of the thickened in the portion adjacent to the heating element 1 and a thermocouple (not shown) is mounted centrally in this portion with connecting leads passing through the wall 15 of the furnace. Alternatively a viewing port for optical temperature measurement could be provided at this point. A second thin-walled graphite cylinder 28 the inside diameter of which is the same as that of the cylinder 2 is mounted on the base plate 16 concentric with and inside the cylinder 27 and extends to a level just below the heating element 1. To reduce conductive heat transfer in the axial direction the wall of the cylinder 28 is made thin but to increase the resistance to oxidation of the thin section at high temperature the upper edge of cylinder 28 is thickened to form a rim 29. Holes 30 in the base-plate 16 provide communication from the annular space between cylinders 27 and 28 to a gas outlet chamber 31 on the lower face of the base-plate 16, the chamber 31 having an outlet 32 to the atmosphere or alternatively to a gas-recirculation system.

A hole 33 centrally in the base plate 16 provides a continuous passage of unchanging diameter between the cylinder 28 and a work-withdrawal passage 34 formed by the inner walls of the chamber 31 and of an annular gas inlet chamber 35 below the chamber 31. The inner wall of the chamber 35 has an annular slot, upwardly and inwardly inclined, corresponding to the slot between the chamfered faces 20 and 24, enabling gas from chamber 35 to be admitted to the passage 34 and to flow upwardly without turbulance. The opening of the lower end of the passage 3 is controlled by an iris diaphragm 36 through which the finished fibre is withdrawn. Unlike the diaphragm 25, the diaphragm 36 is not spring-loaded since it is not intended to make contact with the fibre.

The space in the furnace casing surrounding the cylinder 27 is filled with thermally insulating graphite felt (not shown) so that only graphitic material is exposed to high temperature.

As an example of suitable approximate dimensions for a furnace having a one-inch element, the height may be 6", the annular spacing between the element 1 and the shielding cylinder 27 may be 0.060" and the wall thickness of the cylinder 27, 0.030".

In operation the furnace is filled with argon from the two inlet chambers 21 and 35, and current is passed through the heating element 1 to raise it to the required temperature in the region of 2000-2200°C.

A system for the control of current in response to temperature variation enables a stable temperature to be maintained. Typically an input of 1.4KW and a temperature stability of 0.1°C over a nine-minute period have been recorded. A pre-formed silica feedstock rod, which will be referred to as a pre-form, is passed through the inlet controlled by the iris diaphragm 25 with minimum clearance to limit the outward flow of argon. A silica fibre is drawn from the softened pre-form at a rate typically in the range of 1 to 2 metres/sec. The fibre is withdrawn through the lower iris 36, again with the smallest possible clearance, the mechanical arrangements for drawing the fibre being generally conventional. It is however a common problem that the silica pre-form may not be perfectly straight and it is advantageous for the pre-form to be lowered into the furnace from a gimballed chuck. The lower end of the pre-form may be off-axis in varying degree as it enters the furnace but in response to light radial pressure from the spring-loaded diaphragm 25 the pre-form will be held on the axis of the furnace. The diaphragm 25 is also effective in maintaining a seal around a pre-form which varies in diameter along its length. In principle a static gas filling might be used but some leakage of gas is unavoidable at the irises and consequently a flowing gas system is necessary, and is advantageously arranged in the present invention. The method of construction of the furnace leads to a low value of thermal inertia so that variations of temperature during drawing can be rapidly controlled and when necessary the furnace can be cooled and then returned to operation without delay. Typically a temperature of 2000°C has been recorded three minutes after switching on at room temperature. It will be appreciated that the numerical details of performance quoted in this specification refer specifically to a furnace of the dimensions and construction described herein by way of example.

The invention is based on the need to provide a heating zone which is maintained at a highly stable temperature, which is highly uniform within any diametral plane, and which is highly localised. If these conditions are satisfied there is no deformation of the stock material before it reaches the melting zone, the fibre is drawn with exact cylindrical symmetry and the drawn fibre is immediately cooled without risk of subsequent deformation. The axial temperature profile may safely include steep gradients because of the low value of coefficient of thermal expansion of silica. The contribution of the design of heating element to the uniformity of temperature obtained has already been mentioned. It will be noted that a meandering resistive path around the circumference of a cylinder is connected to the current conductors to form (in the particular embodiment described) two parallel paths which can be equalised if necessary by slight thinning of the wall which has the lower resistance. The number of parallel paths could be increased if desired by providing additional longitudinal slots 7 and, correspondingly, additional lateral slots 6 of appropriately reduced sector angle. The downward flow of gas from the upper annular slot, which passes freely thorugh the slots of the heating element wall but is constrained by the closely spaced wall of the heat-shielding cylinder, also contributes to a uniform distribution of temperature at the element wall. The main heat input to the silica is by radiation from the highly emissive graphite element but the flow of gas at the surface of the softened pre-form is very important in determining the uniformity of the fibre. The flow of silica from the pre-form into the fibre depends on the values of bulk viscosity and surface tension in the tapering region and both properties depend critically on temperature. Any thermal asymmetry, induced for example by turbulence in the gas flow, therefore results in random variations in the cross-section of the fibre. By maintaining the rate of gas input at a low and steady value, together with the use of the annular aperture, a sufficiently smooth flow is obtained. The smoothness of flow is maintained in passing through the upper part of the element assembly due to the cylindrical form of the graphite current conductors. The gas flow also serves to cool these conductors and the terminal connecting bolts which pass through the gas inlet chamber.

A desirably abrupt termination of the heating zone at the lower end is achieved in the embodiment described partly by the use of a suspended element so that no supporting structure is required below the element and partly by the use of controlled gas flow. The first aspect of the control of gas flow for this purpose involves the extraction of the downward flow of heated gas at the annular opening between the two graphite cylinders 27 and 28 immediately below the element 1. The second aspect is the supply of an upward flow of cool gas surrounding the fibre after it emerges from the heated zone. The same precautions are taken as in the upper portion to admit the gas through an annular slit inclined in the direction of flow and to maintain a smooth flow through a smooth walled cylinder. The upward flowing gas is also extracted at the annular opening below the element.

The operation of the furnace has been described in relation to the drawing of silica fibres but the advantages of the furnace would apply equally to the drawing of fibres of other glasses and to other heat treatment processes for which appropriate temperatures and thermal gradients could be provided.

WHAT WE CLAIM IS:

1. An electrical resistance furnace comprising a cylindrical graphite shell, so arranged that in operation the axis of the shell is vertical, the shell having a first portion bounded by one end of the shell and by a diametric plane at which the wall of the shell is pierced by a plurality of uniformly disposed circumferentially extending slots and having a second portion bounded by the other end of the shell and by the diametric plane, the wall of the first portion being pierced by a set of longitudinal slots extending from the circumferential slots and a further set of longitudinal slots extending from said one end, the sets being uniformly interdigitated, to provide a heating element following a regularly meandering resistive path effective to produce a circumferentially substantially uniform heating zone, the wall of the second portion being pierced by a plurality of longitudinal slots uniformly spaced apart and each extending from said other end to a respective one of said circumferential slots, the remaining wall portions providing a like plurality of current conductors connected to the heating element, means for externally connecting said conductors at said other end of the shell, means for continuously enabling process material to be passed axially within the heating element from the upper end of the furnace, means for enabling material that has been processed within the heating element to be withdrawn continuously from the lower end of the furnace, and means for providing an inert gas atmosphere in the furnace.

2. A furnace according to claim 1 including means for suspending the shell within the furnace.

3. A furnace according to Claim 2 in which, when the shell is suspended for operation, the said one portion of the shell lies below the other portion.

4. A furnace according to any of the preceding claims in which the means for providing an inert-gas atmosphere includes gas inlet means and gas outlet means enabling process material being passed into the heating element to be enveloped in cool gas flowing in the same direction and enabling processed material being withdrawn from the heating element to be enveloped in cool gas flowing in the opposite direction.

5. A furnace according to Claim 4 in which the gas inlet means for each required direction of gas flow comprises a circumferential passage formed between two parallel conical surfaces arranged to produce the required direction of gas flow and coaxial with the heating element.

6. A furnace according to Claim 4 or Claim 5 in which the outlet means comprises a circumferential aperture coaxial with and at a level immediately below the heating element.

7. A furnace according to any of the preceding claims in which the means for providing an inert gas atmosphere includes gas recirculation means connected between the outlet and inlet means.

8. A furnace according to any of the preceding claims in which the means for enabling process material to be passed

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axially within the heating element from the upper end of the furnace includes an iris diaphragm at the upper end of the furnace and the means for enabling material that has been processed to be withdrawn from the lower end of the furnace includes an iris diaphragm at the lower end of the furnace, by means of which diaphragms the rate of gas leakage during operation may be minimised.

9. A furnace according to claim 8 in which the iris diaphragm at the upper end of the furnace includes means for enabling inwardly directed and uniformly distributed radial forces to be applied to preformed process material entering the furnace, whereby the process material is constrained to pass along the axis of the furnace.

10. A furnace according to any of the Claims 4 to 9 in which, in the upper portion of the graphite shell, the longitudinal slots are made narrow in relation to the width of the current conductors such that in use the current conductors provide for the flowing gas an effectively continuous cylindrical surface.

11. A furnace according to any preceding claim in which the graphite shell is arranged coaxially within a graphite heat-shielding cylinder, the wall thickness of the cylinder and the radial dimension of the annular gap between the shell and the cylinder being made small relative to the

diameter of the shell.

12. A furnace substantially as hereinbefore described with reference to the accompanying drawing.

13. A furnace according to any preceding claim further including means for continuously advancing a rod-like preform of glassy process material into the upper end of the furnace and means for continuously drawing fibre of the glassy material from the lower end of the furnace.

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1 523 595 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale.*